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Madam Chairman and Members of the Subcommittee, I appreciate the opportunity to testify on the Department of Energy's (DOE or Department) Hydrogen Program activities which support the President's Hydrogen Fuel Initiative. Today I will provide an overview and status update of the Hydrogen Program's accomplishments and plans.

Over two years ago, in his 2003 State of the Union address, President Bush announced a $1.2 billion Hydrogen Fuel Initiative over FY 2004 - 2008 to reverse America's growing dependence on foreign oil by developing the hydrogen technologies needed for commercially viable fuel cells – a way to power cars, trucks, homes, and businesses that could also significantly reduce criteria pollutants and greenhouse gas emissions. Since the launch of the Initiative, we have had many accomplishments on the path to taking hydrogen and fuel cell technologies from the laboratory to the showroom in 2020, following an industry commercialization decision in 2015. The Department's Program encompasses the research and development (R&D) activities necessary to achieve the President's vision, including basic research, applied research and technology development, and learning demonstrations that are an extension of our research. These activities benefit from detailed planning efforts conducted by the Department, and the National Academies study and the Office of Science Basic Research Needs for the Hydrogen Economy workshop, in which two other speakers today, Dr. Bodde and Dr. Crabtree, have made major contributions. I will talk about progress in these areas as we continue on the road to solving the technical barriers that stand between us and this vision of a new energy future.

Hydrogen Vision and Overview

As a Nation, we must work to ensure that we have access to energy that does not require us to compromise our security or our environment. Hydrogen offers the opportunity to end petroleum dependence and to virtually eliminate transportation-related greenhouse gas emissions by addressing the root causes of these issues. Petroleum imports already supply more than 55 percent of U.S. domestic petroleum requirements, and those imports are projected to account for 68 percent by 2025 under a business-as-usual scenario. Transportation accounts for more than two-thirds of the oil use in the United States, and vehicles contribute to the Nation's air quality problems and greenhouse gas emissions because they release criteria pollutants and carbon dioxide.

At the G8 Summit earlier this month, President Bush reiterated his policy of promoting technological innovation, like the development of hydrogen and fuel cell technologies, to address climate change, reduce air pollution, and improve energy security in the United States and throughout the world. The Department's R&D in advanced vehicle technologies, such as gasoline hybrid electric vehicles, will help improve energy efficiency and offset growth in the transportation fleet in the near to mid term. But, for the long term, we ultimately need a substitute to replace petroleum. Hydrogen and fuel cells, when combined, have the potential to provide carbon-free, pollution-free power for transportation.

Hydrogen will be produced from diverse domestic energy resources, which include biomass, fossil fuels, nuclear energy, solar, wind, and other renewables. We have planned and are executing a balanced research portfolio for developing hydrogen production and delivery technologies. The Department's hydrogen production strategy recognizes that most hydrogen will likely be produced by technologies that do not require a new hydrogen delivery infrastructure in the transition to a hydrogen economy, such as distributed reforming of natural gas and of renewable liquid fuels like ethanol and methanol. As research, development, and demonstration efforts progress along renewable, nuclear, and clean coal pathways, a suite of technologies will become available to produce hydrogen from a diverse array of domestic resources. These technologies will be commercialized as market penetration grows and demand for hydrogen increases.

The economic viability of these different production pathways will be strongly affected by regional factors, such as feedstock or energy source availability and cost, delivery approaches, and the regulatory environment so that each region will tailor its hydrogen infrastructure to take advantage of its particular resources. Our ultimate hydrogen production strategy is carbon-neutral and emphasizes diversity. During the transition, net carbon emissions on a well-to-wheels basis, from vehicles running on hydrogen produced from natural gas would be 25 percent less than gasoline hybrid vehicles and 50 percent less than conventional internal combustion engine vehicles. Natural gas is not a long-term strategy because of import concerns and the demands of other economic sectors for natural gas. In the long term, in a hydrogen economy using renewables, nuclear, and coal with sequestration, near-zero carbon light duty vehicles are our goal. I want to emphasize that hydrogen from coal will be produced directly from gasification, not coal-based electricity. This is consistent with technology currently under development for carbon capture and sequestration.

My testimony today will specifically address the Subcommittees' questions:

1. **What progress has been made toward addressing the principal technical barriers to a successful transition to the use of hydrogen as a primary transportation fuel since the Administration announced its hydrogen initiatives, FreedomCAR and the President's Hydrogen Fuel Initiative? What are the remaining potential technical "showstoppers?"**

Progress and Accomplishments

Since the President launched the Hydrogen Fuel Initiative, we have made tremendous progress. The Department has developed a comprehensive technology development plan, the *Hydrogen Posture Plan*, fully integrating the hydrogen research of the Offices of Energy Efficiency and

Renewable Energy; Science; Fossil Energy; and Nuclear Energy, Science, and Technology. This plan identifies technologies, strategies, and interim milestones to enable a 2015 industry commercialization decision on the viability of hydrogen and fuel cell technologies. Each Office has, in turn, developed a detailed research plan which outlines how the high-level milestones will be supported.

We are now implementing these research, development, and demonstration plans:

- Using FY 2004 and FY 2005 appropriations and contingent upon future appropriations over the next 3 years, the Department competitively selected over $510 million in projects ($755 million with cost-share) to address critical challenges such as fuel cell cost, hydrogen storage, hydrogen production and delivery cost, diverse ways of producing hydrogen, as well as research for hydrogen safety, codes and standards.
- Of this total, 65 projects are for hydrogen production and delivery, funded at $107 million over four years. These include hydrogen production from renewables, distributed natural gas, coal, and nuclear sources.
- We initiated three Centers of Excellence and 15 independent projects in Hydrogen Storage at $150 million over five years. The Centers include 20 universities, 9 federal laboratories and 8 industry partners, representing a concerted, multi-disciplinary effort to address on-board vehicular hydrogen storage-- one of the critical enabling technologies for a hydrogen economy. These activities are closely coordinated with the Office of Science research in hydrogen storage.
- To address fuel cell cost and durability, five new projects were initiated at $13 million over three years. A new $75 million solicitation will be released this fall to address cost and durability of fuel cell systems. This is in conjunction with a $17.5 million solicitation currently open focusing on R&D addressing new membrane materials.
- We established a national vehicle and infrastructure "learning demonstration" project at $170 million over six years, with an additional 50 percent cost share by industry. This effort takes some of the research from the laboratory to the real world, and is critical to measuring progress and to providing feedback to our R&D efforts.
- Most recently, to address basic science for the hydrogen economy, 70 new projects were selected by the Office of Science at $64 million over three years to address the fundamental science underpinning hydrogen production, delivery, storage, and use. Topics of this basic research include novel materials for hydrogen storage, membranes for hydrogen separation and purification, designs of catalysts at the nanoscale, solar hydrogen production, and bio-inspired materials and processes. Such research is important for exploring fundamental science that may be applicable in the long term and is responsive to the National Academies' report recommending a shift to more exploratory research.

With these new competitively selected awards, the best scientists and engineers from around the Nation are actively engaged. The stage is now set for results.

Technical Progress

Ongoing research has already led to important technical progress.

- As highlighted by Secretary Bodman in earlier Congressional testimony, I am pleased to report that our fuel cell activities recently achieved an important technology cost goal - the high-volume cost of automotive fuel cells was reduced from $275 per kilowatt to $200 per

kilowatt. This was accomplished by using innovative processes developed by national labs and fuel cell developers for depositing platinum catalyst. This accomplishment is a major step toward the Program's goal of reducing the cost of transportation fuel cell power systems to $45 per kilowatt by 2010.

- In hydrogen production, we have demonstrated our ability to produce hydrogen at a cost of $3.60 per gallon of gasoline equivalent at an integrated fueling station that generates both electricity and hydrogen. This is down from about $5.00 per gallon of gasoline equivalent prior to the Initiative.
- To ensure a balanced portfolio, we must keep sight of our ultimate goal to transfer research to the real world and we have complemented our research efforts with a 'learning demonstration' activity. Most importantly, with the 'learning demonstration' activity we have the key industries that will ultimately have to invest in the hydrogen economy, the auto and energy companies, working together to ensure seamless integration of customer acceptable technology. This activity will evaluate vehicle and refueling infrastructure technologies under real-world conditions and is key to measuring progress toward technical targets and to help focus R&D.

2. What are the research areas where breakthroughs are needed to advance a hydrogen economy? How has the Department of Energy (DOE) responded to the report by the National Academy of Sciences (NAS) calling for an increased emphasis on basic research? How is DOE incorporating the results of the Basic Energy Sciences workshop on basic research needs for a hydrogen economy into the research agenda for the hydrogen initiative?

Starting in FY 2005, the Department of Energy (DOE) Office of Science has been included in the Hydrogen Fuel Initiative in order to focus basic research on overcoming key technology hurdles in hydrogen production, storage, and conversion. The Office of Science-funded research seeks fundamental understanding in areas such as non-precious-metal catalysts, membranes for fuel cells and hydrogen separation, multifunctional nanoscale structures, biological and photoelectrochemical hydrogen production, and modeling and analytical tools.

For example, basic research can help address the critical challenge of hydrogen storage: How do you safely store hydrogen on board a vehicle to enable customer expectations of greater than 300 mile driving range, without compromising passenger or cargo space? The National Academy of Sciences recommended "a shift…away from some development areas towards more exploratory work" to address issues like storage, stating that "the probability of success is greatly increased by partnering with a broader range of academic and industrial organizations…" Through the Department's "Grand Challenge" solicitation, a "National Hydrogen Storage Project" was established to broaden our scope. The new awards in basic research, with an additional $20 million for 17 projects over 3 years supported by the Office of Science, are integrated into this national project and provide value in developing a fundamental understanding of hydrogen interactions with materials. These multi-disciplinary efforts focused on *materials*-based technology for hydrogen storage, directly address the recommendations from the Basic Energy Sciences workshop on basic research needs for a hydrogen economy. By implementing the NAS recommendations, recent progress in materials discovery and technology allows hydrogen to be stored at low pressures and modest temperatures. Further basic and applied research will

lead to better fundamental understanding and engineering solutions to address some of the key storage issues such as charging and discharging hydrogen at practical temperatures and pressures. Rather than 'stand alone' test tube research, we have an integrated effort to address basic, applied, and engineering sciences to develop materials and systems for storing hydrogen.

We face another set of challenges in hydrogen production. In this area, our research efforts are focused on reducing cost, improving energy efficiencies, and ensuring a diversity of pathways based on domestic resources for energy security that do not result in green house gas emissions. Some pathways are further along in development and will be commercially viable sooner than others. For the transition, we envision producing hydrogen from natural gas or renewable liquids such as ethanol, at the fueling point, thus eliminating the need for a dedicated hydrogen distribution network. Centralized hydrogen production from coal with sequestration, biomass, nuclear, and distribution networks can follow later once market penetration justifies the capital investment required. Basic science is critical to understanding materials performance, failure mechanisms, and theoretical technology limits. The basic research component of the program contributes to longer-term concepts such as photocatalytic including biological hydrogen production and direct photoelectrochemical conversion to produce hydrogen. In fact, we have nearly $20 million of federal funding in new projects selected by the Office of Science on solar hydrogen production, membranes for separation and purification, and for bio-inspired materials and processes.

As for fuel cells, key issues are cost and durability. Significant progress has been made by national laboratories as well as industry to reduce the amount of platinum, and hence cost, within the fuel cell electrode. In addition to the targeted activities in fuel cells previously mentioned, the Office of Science has initiated new basic research projects on the design of catalysts at the nanoscale and membrane materials related to fuel cell applications. More effective catalysts, combined with better techniques for fabricating these membrane electrode assemblies and new strategies for improved durability of fuel cells, will enable us to meet the aggressive cost and performance targets we have set for fuel cells. We are also expanding our activities to include manufacturing issues that will help take these new technologies from the laboratory to the marketplace.

3. The NAS report suggested that the research agenda should be developed with future policy decisions in mind. How has DOE increased its policy analysis capabilities as recommended by the NAS? How will the results of that analysis be applied to the research agenda?

I would like to emphasize that this Program is a research effort. However, as stated earlier, in response to the National Academies' recommendation, the Program has established the Systems Analysis and Integration effort to provide a disciplined approach to the research, design, development, and validation of complex systems. A fact-based analytical approach will be used to develop a balanced portfolio of R&D projects to support the development of production, delivery, storage, fuel cell, and safety technologies. Through analysis, the impact of individual components on the hydrogen energy system as a whole will be evaluated and the interaction of the components and their effects on the system will be assessed. Systems Analysis and

Integration efforts will be available to examine and understand the cost implications of policy and regulations on technology R&D direction. Analysis of various scenarios for hydrogen production and delivery is critical to the transition plan for developing the infrastructure and carbon-neutral hydrogen resources for a hydrogen economy. The planned analysis efforts will be valuable in providing rigorous data and potential guidance for policy decisions in future years.

4. How is DOE conducting planning for, and analysis of, the policy changes (such as incentives or regulation) that might be required to encourage a transition to hydrogen? What other agencies are involved in planning for, or facilitating, such a transition?

Currently, the focus of the DOE Hydrogen Program is research and development to address key technical challenges. Research and development on the codes and standards necessary to implementing hydrogen and fuel cell technologies will form a scientific and technical basis for future regulations. We are actively working with the Department of Transportation and interface with Standards Development Organizations (SDOs) and Codes Development Organizations (CDOs) on safety, codes and standards.

As part of the Systems Analysis efforts, we have started to model and explore options and pathways to achieve a successful transition to hydrogen. This effort is in collaboration with the Vehicle Technology Office and the overall Energy Efficiency and Renewable Energy modeling efforts. The Energy Information Administration (EIA) is also providing guidance. This work includes the incorporation of rigorous hydrogen production, delivery, and vehicle technology components into the National Energy Management System (NEMS) model architecture, as well development of a more detailed transportation sector model that includes conventional, hybrid, and alternative fuel options. These modeling efforts will also allow us to examine the potential impacts of policy and regulations on the introduction and long term use of hydrogen.

Now I will talk about our partners and our future plans.

We are working with partners on all fronts to address the challenges to a hydrogen economy. Under the FreedomCAR and Fuel Partnership, DOE is collaborating with the U.S. Council for Automotive Research (USCAR) and five major energy companies to help identify and evaluate technologies that will meet customer requirements and establish the business case. Technical teams of research managers from the automotive and energy industries and DOE are meeting regularly to establish and update technology roadmaps in each technology area.

An Interagency Hydrogen R&D Task Force has been established by the White House Office of Science and Technology Policy (OSTP) to leverage resources and coordinate interrelated and complementary research across the entire Federal Government. In 2005, the Task Force has initiated a plan to coordinate a number of key research activities among the eight major agencies that fund hydrogen and fuel cell research. Coordination topics include novel materials for fuel cells and hydrogen storage, inexpensive and durable catalysts, hydrogen production from alternative sources, stationary fuel cells, and fuel-cell vehicle demonstrations. The Task Force has also launched a website, Hydrogen.gov. In the coming year, the OSTP Task Force plans to sponsor an expert panel on the contributions that nanoscale research can make to realizing a Hydrogen Economy.

Last year, we announced the establishment of the International Partnership for the Hydrogen Economy, or the IPHE. IPHE, which now includes 16 nations and the European Commission, establishes world-wide collaboration on hydrogen technology. The nations have agreed to work cooperatively toward a unifying goal: practical, affordable, competitively-priced hydrogen vehicles and refueling by 2020; and projects involving collaboration between different countries are being proposed and reviewed for selection.

Toward the Hydrogen Future

The Department is looking to the future as well. Just as we have made tremendous progress, we plan to have significant advances to report next year on the R & D projects we have launched through the solicitations I mentioned. The progress will be tracked using performance-based technical and cost milestones that provide clear and quantifiable measures. We will report this progress next year to this Subcommittee, and annually to Congress and to the Office of Management and Budget. In fact, as we speak, the NAS is completing its biennial review of the program. We anticipate more valuable feedback and will have more details to report in the coming months.

For the critical targets, it is important that we verify our progress in a way that is independent and transparent. In Fiscal Year 2006, the major technical milestones will be assessed using a rigorous methodology established by the Hydrogen Program.

- First, in Hydrogen Storage, we will determine the maximum storage potential of cryogenic-compressed hydrogen tanks and the feasibility of this technology towards meeting DOE's 2010 targets.
- Second, in Fuel Cells, we will evaluate fuel cell cost per kilowatt using current materials to determine if $110/kilowatt is feasible towards meeting the 2010 target of $45/ kilowatt (assuming high volume manufacturing).
- And third, in Hydrogen Production, we will determine if the laboratory research will lead to $3 per gasoline gallon energy equivalent (gge) using a distributed natural gas reformer system.

In addition to measuring progress, we continue to develop and improve processes to facilitate innovation and to accelerate R&D. For instance, we plan an annual solicitation, starting in 2006, in the critical area of hydrogen storage to complement the Centers of Excellence. This will improve our flexibility to continuously evaluate new ideas and rapidly fund competitively selected projects.

Validation of fuel cell vehicle and hydrogen infrastructure technologies under 'real world' operating conditions is essential to track progress and to help guide research priorities. Technology and infrastructure validation will provide essential statistical data on the status of fuel cell vehicle and infrastructure technologies relative to targets in the areas of efficiency, durability, storage system range, and fuel cost. This activity will also provide information to support the development of codes and standards for the commercial use of hydrogen, and feedback on vehicle and infrastructure safety. Through cost-shared partnerships with the energy industry, Fiscal Year 2006 activities include opening eight hydrogen fueling stations, and validating performance, safety, and cost of hydrogen production and delivery technologies. By

2009, the program is expected to validate fuel cell vehicle durability of 2,000 hours, a 250-mile vehicle range, and full-scale hydrogen production cost of less than $3.00 gge.

In addition, a critical need for lowering the costs of hydrogen and fuel cells is high volume manufacturing processes and techniques. Manufacturing R&D challenges for a hydrogen economy include developing innovative, low-cost fabrication processes for new materials and applications and adapting laboratory fabrication techniques to enable high volume manufacturing. The Hydrogen Program is working with Department of Commerce and other Federal agencies to create a roadmap for developing manufacturing technologies for hydrogen and fuel cell systems as part of the President's Manufacturing Initiative. The roadmap will help to guide budget requests in Fiscal Year 2007 and beyond. This work is part of the Interagency Working Group on Manufacturing R&D, which is chaired by OSTP and includes 14 Federal agencies. The working group has identified nanomanufacturing, manufacturing R&D for the hydrogen economy, and intelligent and integrated manufacturing systems as three focus areas for the future. Manufacturing R&D for the hydrogen economy will be critical in formulating a strategy to transfer technology successes in the laboratory to new jobs, new investments, and a competitive U.S. supplier base in a global economy.

Successful commercialization of hydrogen technologies requires a comprehensive database on component reliability and safety, published performance-based domestic standards, and international standards or regulations that will allow the technologies to compete in a global market. Initial codes and standards for the commercial use of hydrogen are only now starting to be published. Research will be conducted in Fiscal Year 2006 to determine flammability limits and the reactive and depressive properties of hydrogen under various conditions, and also to quantify risk. Through such efforts, critical data will be generated to help write and adopt standards and to develop improved safety systems and criteria.

Conclusion

Madam Chairman, all the panelists here today will agree that achieving the vision of the hydrogen energy future is a great challenge. The DOE Hydrogen Program is committed to a balanced portfolio, conducting the basic and applied research necessary to achieve this vision. It will require careful planning and coordination, public education, technology development, and substantial public and private investments. It will require a broad political consensus and a bipartisan approach to achieving the President's vision. We appreciate the leadership taken by the Senate, and most recently the House, in establishing Hydrogen and Fuel Cell Caucuses. By being bold and innovative, we can change the way we do business here in America; we can change our dependence upon foreign sources of energy; we can address the root cause of greenhouse gas emissions; we can help with the quality of the air; and we can make a fundamental difference for the future of our children. This Committee in particular has been instrumental in providing that kind of leadership over the years, and we look forward to continuing this dialogue in the months and years ahead.

We at the Department of Energy welcome the challenge and opportunity to play a vital role in this Nation's energy future and to help address our energy security challenges in such a fundamental way. This completes my prepared statement. I would be happy to answer any questions you may have.